A BEMS-ASSISTED COMMISSIONING TOOL TO IMPROVE THE ENERGY PERFORMANCE OF HVAC SYSTEMS

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ABSTRACT

The evolving capabilities of Building Energy Management Systems (BEMS) offer new opportunities to automate some parts of the commissioning process and can generate benefits over the entire life of a building. These benefits include a reduction of process cost and manual effort on site, improved quality assurance process and the adoption of automated energy audit capabilities to improve overall building performance.

This paper presents the concept for a new automated commissioning tool that verifies and optimizes the performance of building HVAC systems using the capabilities of BEMS. The tool is applicable mainly to commercial and institutional buildings. In its simplest form, the tool monitors building control data and stores it in a structured database to be used on-line or upon request. Data resulting from standardized test procedures invoked manually or automatically are also stored in the database. A reasoning algorithm performs an intelligent analysis of the monitored data and also performs additional automated commissioning of HVAC components and systems, identifying faults, diagnosing them, and evaluating the potential energy efficiency improvements. The process is completed by sending detailed comprehensive reports to the user.

This paper also includes an example showing how an automated BEMS-assisted commissioning tool can potentially be applied to improve the energy performance of variable-air-volume fan systems.

KEYWORDS

Commissioning, HVAC, Building energy management system, energy management

1. INTRODUCTION

It is accepted that the initial, retro, or continuous commissioning of HVAC systems is a proven process that reduces energy consumption and improves occupant comfort in buildings. Claridge et al. (1998) have shown that the use of the existing building control system for commissioning resulted in 25% energy cost savings. In spite of documented benefits, commissioning is still regarded as a minor activity in building operation and remains a one-time task that is performed during the building construction phase. Building professionals and owners attribute this situation principally to the cost associated with the commissioning process as well as the related difficulty of finding qualified resources to execute it.

The evolving capabilities of Building Energy Management Systems (BEMS) can help to circumvent the barriers to commissioning by offering opportunities to automate some parts of the commissioning process. Automation or semi-automation of certain aspects of the commissioning process has the potential to reduce costs for commissioning, thereby leading to more widespread application of the process. Furthermore, automating this essentially manual process could allow its application on a regular basis, generating benefits over the entire life of a building. Developing a detailed systematic automated approach will improve the quality assurance process and could even integrate energy audit capabilities that improve the overall performance of buildings. In this context, this paper presents the concept for a new automated commissioning tool that verifies and optimizes the performance of building HVAC systems using the capabilities of BEMS. This tool is applicable mainly to commercial and institutional buildings.

2. BACKGROUND

The work presented in this paper describes Canada's contribution to the International Energy Agency's

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(IEA 2001a) Annex 40, Commissioning of Building HVAC Systems for Improved Energy Performance. Annex 40 is a research project within the framework of the Energy Conservation in Building and Community Systems (ECBCS) program of the IEA. The objective of Annex 40 is to develop, validate and document tools for commissioning of buildings and building services that will facilitate verifying and optimizing the performance of energy systems within a building. Subtask C of Annex 40 concentrates on the development of automated commissioning tools that use the capabilities of BEMS.

The main issues, market factors, barriers and opportunities for the development of BEMS-assisted commissioning tools were identified during the preparation phase of IEA Annex 40. This information was primarily drawn from surveys of BEMS manufacturers, installers, commissioning practitioners, and clients that were conducted in Canada (Marbek 2001), France, Japan, Switzerland and the USA.

It was concluded that commissioning tools currently used in practice are limited to document templates intended to be used primarily during the construction and acceptance phases of the building design and delivery process. Automated tools are almost non-existent or are at the embryonic stage of research. It appears that a market opportunity for BEMS-assisted commissioning tools exists; however, market factors, barriers and opportunities vary from country to country and are closely linked to the potential users and the commissioning phase addressed (Marbek 2001).

The development of the BEMS-assisted commissioning tool presented in this paper is a continuation of work that began under IEA Annexes 25 and 34 (IEA 1996, IEA 2001b), which focused on developing and testing techniques to detect and diagnose faults of HVAC equipment using real time data. A result of these research efforts is the Diagnostic Agent for Building Operators (DABO) (Choinière 2001), developed by the CANMET Energy Technology Centre - Varennes (CETC-V). DABO is a software package that uses a hybrid technology composed of conventional and artificial intelligence techniques to ensure optimum operation of building systems. DABO resides on any PC and analyzes incoming data from the building energy management system. DABO consists of four interlocking modules (Figure 1): the building energy agent, the fault detection and diagnostic agent, the commissioning agent, and the condition-based maintenance agent.

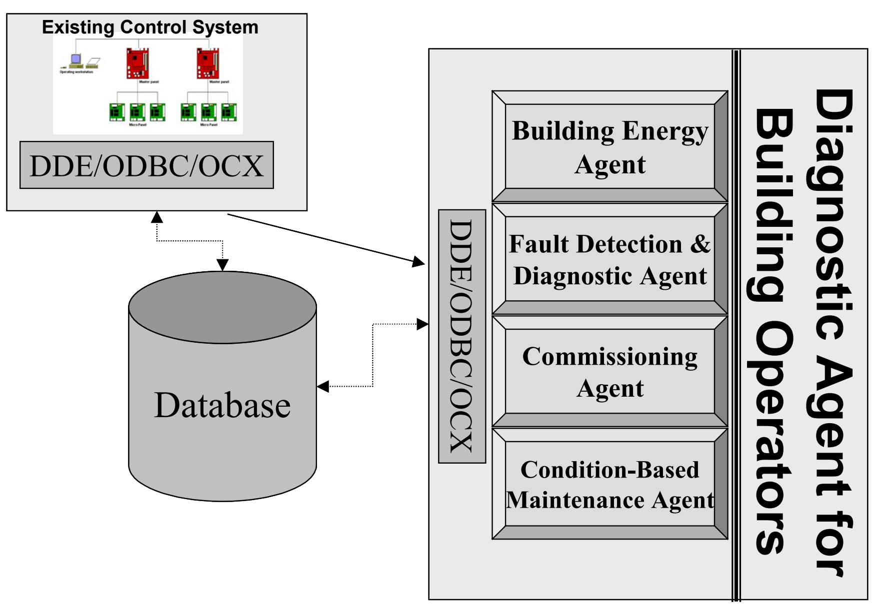

Figure 1: General architecture of the Diagnostic Agent for Building Operators developed by the CANMET Energy Technology Centre.

DABO's fault detection and diagnostic module applies primarily to variable-air-volume (VAV) boxes and air handling units. A combination of control loop indices and expert rules that are directly embedded in the controller are used to detect and diagnose VAV box faults. The fault detection and diagnosis of air handling units is a rule-based system that is integrated within DABO, which provides the communication link between the database of measured building control data and the expert system's working memory. Specific applications of the fault detection and diagnostic (FDD) methods implemented in DABO are described further in Section C of IEA 2001b.

A review of studies focusing on FDD methods applied to air handling units and VAV boxes is provided in House et al. (2003). Automated FDD tools passively monitor and analyze data that are collected from the BEMS and report on faulty or inefficient operation of HVAC systems and control components. Piette and Friedman (2002) provide a list of typical faults that can be detected using FDD tools and BEMS data and compare several diagnostic tools. In addition to DABO, automated FDD tools that have emerged in recent years include:

- PACRAT (Arney et al. 2003), the Performance and Continuous Re-Commissioning Analysis Tool, performs FDD of air handling units, chillers, hydronic systems, and assists with building system optimization through energy accounting and monitoring and verification tasks
- Whole Building Diagnostician (Katipamula et al. 1999), which encompasses one module that monitors whole building energy use, and another module that performs FDD of air handling units and economizer controls, and
- Honeywell HVAC Service Assistant (Rossi et al. 2003), which is a portable diagnostics tool for unitary HVAC equipment.

Some automated commissioning tools under development take the capabilities of passive FDD tools one step further by actively sending control signals to the BEMS to invoke functional performance tests aimed at providing a deeper and more accurate fault diagnosis and automatically take corrective action to compensate for faulty behavior (Brambley et al. 2002; Brambley et al. 2003). The National Institute of Standards and Technology is developing a Commissioning Test Shell that establishes communication links with the control system using the BACnet communication protocol, enabling the development and testing of passive and active commissioning tools (Castro et al. 2003). The test shell can actively override control system commands to invoke functional tests using a scripting capability.

3. BUILDING ENERGY MANAGER TASKS

Building energy management is gaining greater importance with the expansion of owner building assets, complexity of building energy systems, complexity of energy billing methods, rising energy costs, and environmental concerns. In this context, the building energy manager aims to ensure that buildings operate at their optimum energy performance levels. This state is only achieved when buildings consume the minimum energy at the lowest cost while simultaneously considering the building's function and comfort level, available energy source(s), building energy systems and energy rates. To be efficient, many tasks of an energy management plan must be performed continuously, an undertaking that can be facilitated by monitoring the condition of HVAC systems and building energy consumption using a BEMS. At this level, the functions of the energy manager are similar to the implementation of a continuous commissioning process, defined as an on-going process to resolve operating problems, improve comfort, optimize energy use and recommend retrofits, if necessary. These tasks could make the use of a BEMS-assisted continuous commissioning tool very beneficial.

To show which functions of a building energy management plan can benefit from automation, one type of energy management plan is presented (Choinière 1995). The plan is used by the largest building owner in Canada, Public Works and Government Services Canada, in its day to day operation. Illustrated in Figure 2, the plan is structured by field of activity: (1) Accounting Management, (2) Optimization of existing buildings, and (3) Optimization of new buildings.

Accounting Management groups actions to be taken to ensure that the energy currently used is at the minimal cost. It includes the verification and monitoring of energy invoices and consumption, co-ordination with building operators, and the purchase of energy. Some of these actions could be supervised on a monthly basis using energy accounting software.

Optimization of existing buildings is a logical complement to the accounting management task. At this level, actions aim at optimizing the energy consumption. These actions include the recommissioning and energy auditing of buildings,

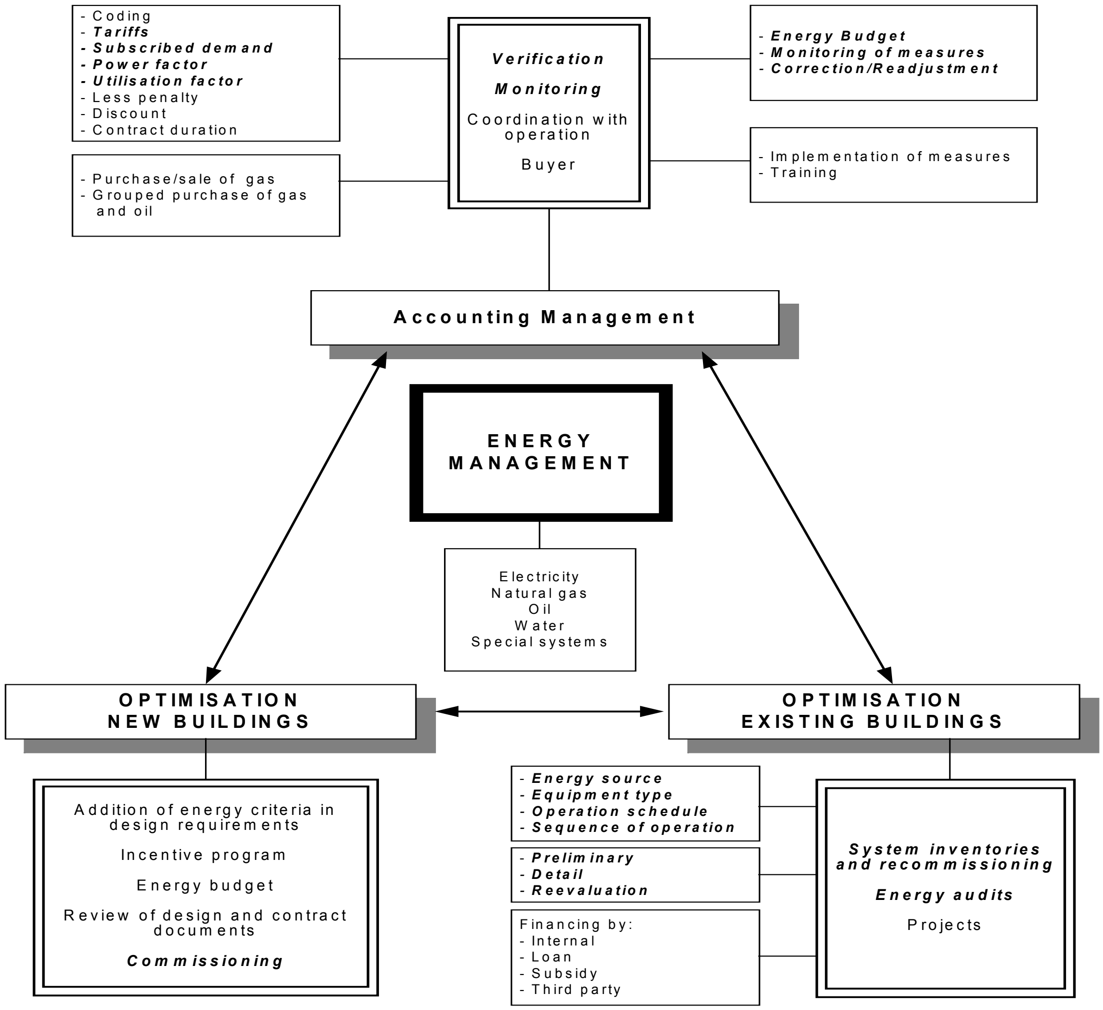

Figure 2: Building energy management plan. (Choinière 1995)

followed by the implementation of energy saving measures.

Optimization of new buildings is a similar process as in existing buildings, with the difference that in new buildings opportunities for optimization are anticipated during the design stage. Usually optimization at this stage is easiest to achieve mainly because the payback is highest and implementation of measures easiest. Tasks include the addition of energy criteria in the design requirements, preparation of the energy budget, review of design and contract documents, and finally the commissioning of energy systems.

The tasks shown in italics in Figure 2 represent the functions that could be performed by a BEMS-assisted continuous commissioning tool to facilitate the work of the energy manager. The heart of the tool is the monitoring of all HVAC equipment (e.g., terminal unit, air handling unit and plant equipment) and building energy meters. This data could be processed to serve two main functions: (i) as input to a fault detection and diagnosis tool on energy use, energy rates, control set points, sequence of operation and expected energy savings, and (ii) as input to various optimization processes such as specific continuous commissioning tests and energy auditing procedures.

4. BEMS-ASSISTED COMMISSIONING TOOL

The BEMS-assisted commissioning tool is designed to perform the functions described in the energy management plan (Figure 2). The tool is a new module of the Diagnostic Agent for Building Operators, which serves as the interface between the end-user (e.g., building operator, commissioning agent, energy manager) and the control system (BEMS). It monitors building control data, storing it in a structured database to be used on-line or upon request. Data resulting from standardised test procedures invoked manually or automatically will also be stored in the database. The database will also function as a server for reasoning algorithms that perform intelligent analyses of the monitored data, perform additional automated tests of components and systems, identify faults and diagnosing them, and evaluate potential improvements in energy efficiency. The tools can produce reports adapted to the different partners involved in the commissioning process.

The standardized test procedures will be performed at three levels. At the first level, a component analysis of individual HVAC devices and equipment will be performed automatically using current commissioning and FDD procedures to verify their proper operation. These tests would likely be short term, on the order of minutes to hours. The second level of testing consists of an integrated system analysis to verify the operation and energy performance of the overall HVAC system over a longer period of time (e.g., hours, days, weeks or months). One could envision these first two levels of tools complementing each other like top-down and bottom-up approaches commonly used for fault detection and diagnosis. The third level will perform basic energy auditing and will evaluate potential energy savings on specific devices.

Figure 3 presents an example where a BEMS-assisted commissioning tool could be applied to improve the energy performance of variable-air-volume fan systems (VAVS) using DABO. This type of system is commonly used for HVAC application in buildings and its performance is a function of many factors that vary depending on the time of day, time of year, heating and cooling source, and building occupancy. Without constant supervision and monitoring, it is almost impossible to readjust the system parameters to keep its operation optimal.

Typically, a VAVS consists of an air handling unit (AHU) with an air filter section, cooling and heating coils, outdoor, mixing and return air dampers, supply fan, return fan, humidifier and air plenum section. Supply air from the AHU is ducted to VAV boxes, which are the end devices of the ventilation system. Their purpose is to control the amount of airflow in local rooms in order to maintain a room temperature set point. Since VAVS is primarily used for cooling applications, other heating sources such as perimeter heaters or reheat coils are often used to ensure proper zone temperature.

Zone temperature is controlled by modulating the amount of primary cold air through the VAV boxes as a function of the cooling load. Maximum air flow is provided to meet the peak cooling demand in the

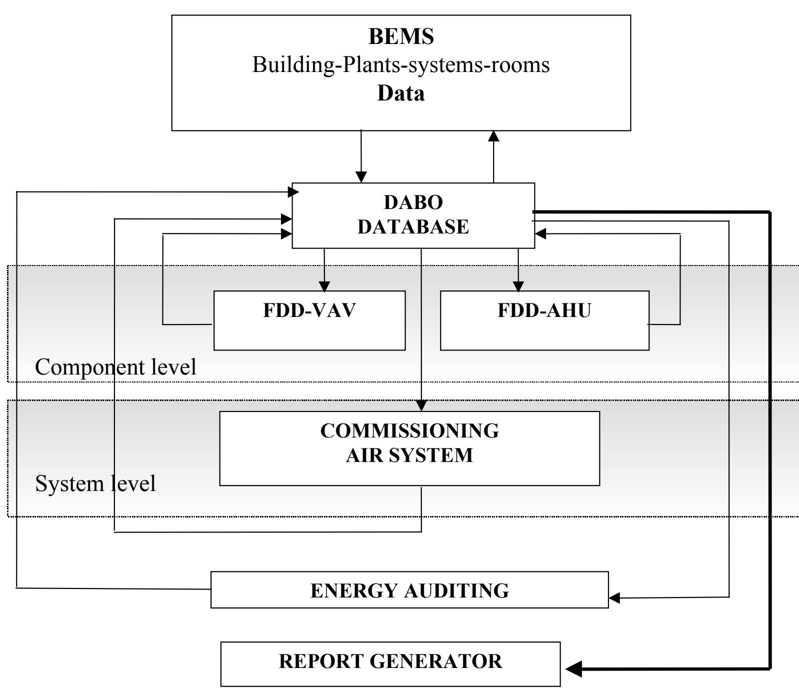

Figure 3: Structure of the continuous commissioning tool for variable air volume fan systems embedded in DABO.

space. As space cooling demand decreases, the airflow rate is reduced up to a given minimum airflow rate. A reheat coil or perimeter heater is activated if less cooling is required. The unit is usually pressure independent and attempts to maintain a constant static pressure at the VAV box inlets. A static pressure controller modulates the capacity of the supply fan and maintains the supply duct pressure set point. The return fan is controlled by a return airflow controller. In this example VAVS, the return airflow set point is calculated as the measured supply airflow minus both the design airflow through the local exhaust fan and the amount of airflow required for building pressurisation. The unit is sequenced during the occupied period to provide heating, cooling, and ventilation based upon control of the discharge air temperature to meet the return air set point. An enthalpy control economiser allows cooling with cooler air, and humidification is provided to maintain a minimum set point of the relative humidity in the return air during winter.

Table 1 summarizes the actions that a BEMS-assisted continuous commissioning tool would perform for the fault detection and diagnosis, evaluation and analysis of the VAVS at each level.

5. CONCLUSIONS

Monitoring the energy performance of buildings is a growing priority for building owners and operators. This is not easy due to the enormous amounts of data produced by BEMS, and the extensive analysis required to evaluate the data. A comprehensive energy management plan will ensure that buildings operate at their optimized energy performance levels, while maintaining comfort conditions for occupants and minimising energy costs. The proposed BEMS-assisted continuous commissioning tool will perform the high level data analysis tasks required to implement an energy management plan and will inform the operator and energy manager on the building's state.

The commissioning tool is in its final stages of development and will be installed at the Dorval International Airport in Montreal to commission an extension of the airport.

Table 1. Functions of BEMS-assisted commissioning tool for VAV system.

Component Level – Fault Detection and Diagnosis
• Temperature, CO_2 and humidity sensor faults (outside, return, mixed and supply air) • Fan, damper and actuator faults (mixing, exhaust and outdoor air) • Valve and actuator faults (heating, cooling and humidifier) • Control logic (heating, cooling and humidifier valves, mixing and outdoor damper, supply air temperature, fan volume control devices) • Coil (heating, cooling and humidifier)
System Optimization Level – Fault Detection and Diagnosis
• Non optimum AHU start up time, purge time, supply air temperature, supply air pressure • Non optimum fresh air supply • Under design capacity of air handling unit and room control devices
Energy Auditing Level – Analysis
• Daily, monthly and yearly utilisation factor (fan, AHU heating and cooling coil, room control device levels) • Over and under design capacity • Input to plant optimization tool • Evaluation of basic energy savings improvements (variable speed drive on fan, peak shaving, etc.)

6. ACKNOWLEDGEMENTS

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7. REFERENCES

Choinière D. 1994. Gestion d'énergie chez Travaux publics et services gouvernementaux Canada. *La maîtrise de l'énergie* **9:4**, 25.

Choinière D. 2001. Un agent de détection et diagnostic de fautes pour les bâtiments. *Congrès de l'Association québécoise pour la maîtrise de l'énergie*. Quebec City, Quebec, Canada.

Claridge D. E., M. Liu, W. D. Turner, Y. Zhu, M. Abbas, and J. S. Haberl. 1998. Energy and Comfort Benefits of Continuous Commissioning in Buildings. *Proceedings of the International Conference Improving Electricity Efficiency in Commercial Buildings*. September 21-23.

IEA. 1996. International Energy Agency. Annex 25: Real Time Simulation of HVAC Systems for Building Optimization, Fault Detection and Diagnosis. Final Report. Editor Juhani Hyvarinen.

IEA. 2001a. International Energy Agency. Annex 40: Commissioning of Buildings and HVAC Systems for Improved Energy Performance. http://www.commissioning-hvac.org.

IEA. 2001b. International Energy Agency. Annex 34: Computer-Aided Evaluation of HVAC System Performance. Final Report. Editors Arthur Dexter and Jouko Pakanen. International Energy Agency.

Marbek Resource Consultants Ltd. 2001. Review of Commissioning Processes and Tools. Prepared under contract with CANMET Energy Technology Centre – Varennes, Natural Resources Canada.

House, J. M., K. D. Lee, and L. K. Norford. 2003. Controls and Diagnostics for Air Distribution Systems. *Journal of Solar Energy Engineering.* Vol. 125, pp. 310-317.

Piette M. A. and H. Friedman. 2002. Data Mining: Using HVAC Diagnostic Tools and EMCS Data. *Networked Controls*. July.

Arney, W. M., J. J. Santos, E. L. Brightbill, and L. Lister. 2003. PACRAT: The Latest in Automated Diagnostics. *Proceedings of the 11th National Conference on Building Commissioning*. Palm Springs, CA.

Katipamula, S., R. G. Pratt, D. P. Chassin, Z. T. Taylor, K. Gowri, and M. R. Brambley. 1999. Automated Fault Detection and Diagnostics for Outdoor-Air Ventilation Systems and Economizers: Methodology and Results from Field Testing. *ASHRAE Transactions* 105(1): 555-567.

Rossi, T. M., J. D. Douglas, and M. V. A. Bianchi. 2003. Evaluating and Documenting the Performance of Unitary HVAC Equipment with the Honeywell HVAC Service Assistant. *Proceedings of the 11th National Conference on Building Commissioning*. Palm Springs, CA.

Brambley, M. R., R. Briggs, S. Katipamula, C. Dasher, L. Luskay, and L. Irvine. 2002. Investigating Potential Strategies for Automating Commissioning Activities. *Proceedings of the 10th National Conference on Building Commissioning*. Chicago, IL.

Brambley, M. R. and S. Katipamula. 2003. Automating Commissioning Activities: An Update with an Example. *Proceedings of the 11th National Conference on Building Commissioning*. Palm Springs, CA.

Castro N. S., M. A. Galler, and S. T. Bushby. 2003. A Test Shell for Developing Automated Commissioning Tools for BACnet Systems. *Proceedings of the 11th National Conference on Building Commissioning*. Palm Springs, CA.